

Studies of the Tsushima Current

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LONG-TERM GOALS

To build an understanding of nature of poleward flowing warm water pathways along eastern boundaries of the ocean.

OBJECTIVES

To understand the structure, interannual and seasonal variability of the Japan Sea's Tsushima Current and its relationship to the upstream condition, the Japan Sea warm core eddy field and subpolar front.

APPROACH

To achieve the objectives, we have adopted a two-pronged approach employing both data analysis and modeling.

A. Data Analysis: Using high quality *in situ* hydrographic data and TOPEX Poseidon altimetric data, define the mean, seasonal and interannual variability of Tsushima Current shear and transport in the context of the geometry of the eastern boundary of the Japan Sea and distribution of warm core eddies.

B. Modeling: Through analytical modeling, we examine the dynamics of Tsushima Current as it interacts with the strait geometry, the boundary curvature, and surface cooling. We also investigate the dynamics of subduction along the sub-polar front and its linkage to the intra-thermocline eddies.

WORK COMPLETED

A. Data Analysis:

1. Intra-Thermocline Eddies: Using data obtained by the JES program in spring/summer 1999 and winter 2000, by the *Hakuho-maru* and *Revelle* cruises, along with archived data including the suite of AXBT profiles, a family of sub-surface eddies within the warm regime of the Japan Sea are identified. The characteristics of these intra-thermocline eddies are described. This work is now 'in press': Gordon, A. L., C. F. Giulivi, C. M. Lee, H. H. Furey, A. Bower and L. Talley (2002) Japan/East Sea Intra-thermocline Eddies. *Jour of Phys Oceanogr*.

2. Sea Level Slope: During the first phase of our JES research we gathered all available hydrographic and TOPEX POSEIDON (T/P) data within the Sea of Japan, and developed methods to view and merge these data sets into a form that allows us to investigate the sea surface geostrophic currents of the Tsushima Current. We have merged the hydrographic data mean climatic dynamic height (0/200) array with the T/P sea surface height anomaly (SSHA) data thus converting the latter into an approximation of the absolute sea level. We have worked with the late 1992 to mid-1997 T/P data set, but we will now with our methods in place, extend the analysis to the more recent T/P data.

B. Modeling:

Branching of the Tsushima Current: We have proposed a robust mechanism for the branching of the Tsushima Current as it exits the Tsushima Strait. The research has resulted in a paper published in the Journal of Physical Oceanography.

Subduction and the generation of intra-thermocline eddies (ITEs): We have completed a dynamical study of the subduction along a mid-ocean front and its linkage to ITEs. The findings are contained in a paper currently in press at the Journal of Physical Oceanography.

Cooling of the Tsushima Current: We are presently investigating the cooling effect on the poleward flowing Tsushima Current, and how the branching feature may be maintained or even enhanced despite the bottom friction.

Generation of the Tsushima eddies: We have proposed a novel mechanism of eddy generation when a buoyant current interacts with a curved boundary. We are in the process of numerically demonstrating the mechanism, which may be relevant to generation of the Tsushima eddies.

RESULTS

A Data Analysis:

1. Intra-Thermocline Eddies: [collaborative research with: Craig Lee (UW), Amy Bower and Heather Hunt Furey (WHOI), Claudia F. Giulivi (LDEO) and Lynne Talley (SIO)]: Intra-thermocline eddies (ITE) with a diameter of 100 km, of thickness greater than 100-m are observed within each of the three quasi-stationary meanders of the Tsushima Current of the Japan/East Sea. The core temperature is near 10°C with a salinity of 34.12. Because of the compensatory baroclinicity of the upper and lower boundaries of the ITE lens, the anticyclonic geostrophic flow within the ITE has minor sea level expression. The ITE core displays positive oxygen and negative salinity anomalies in comparison to surrounding thermocline water, indicative of formation from winter mixed layer water along southern side of the Japan/East Sea subpolar front. The winter mixing layer is then overridden, or slips below, the regional upper thermocline stratification with its characteristic salinity maximum core layer. Winter mixed layers off the coast of Korea, within the western most quasi-stationary meander closely match the intra-thermocline eddy characteristics, and is considered as a potential source region. Other sources may be present along the southern boundary of the subpolar front, including a frequently observed warm eddy over the western side of Yamato Rise.

2. Sea Level Slope: The sea surface slope reveals significant annual and interannual variability. Higher sealevel with a stronger Tsushima Current occurs in the latter half of year. Frequent isolated high sealevel is observed north of the main axes of the Tsushima Current, denoting the presence of warm eddies. Strong variability along three quasi-stationary meanders of the Tsushima Current (130°E, 134°E and 137°E) clearly seen in SST images, can also be identified in sealevel. Interannual variability occurs in the spatial characteristics of the Tsushima Current.

B. Modeling:

Branching of the Tsushima Current: Through a reduced-gravity model, we have examined the dynamics of a buoyant flow through a strait. It is demonstrated that the combined effect of sill friction and stretching of the buoyant layer as it exits the strait may cause the flow to branch. Since the required condition for branching is amply satisfied by the Tsushima Current, the mechanism provides a plausible explanation of the observed branching.

Subduction and the generation of intra-thermocline eddies (ITEs): Motivated by recent observation in the Japan Sea, we have conducted an analytical study of the subduction along a mid-ocean front, and its linkage to ITEs. It is found that subduction is necessitated by the advective-diffusive balance of vorticity, and the mis-match of the potential vorticity of the subducted water and the interior thermocline may cause the generation of ITEs. Through entrainment cooling, ITEs would leave their imprints in the surface layer, which may explain the quasi-stationary meandering appearance of the sub-polar front.

Cooling of the Tsushima Current: Through a reduced-gravity model, we are investigating the effect of surface cooling on a buoyant boundary current. It is found that through mass and vorticity balances, such cooling would redistribute the kinetic energy from the frontal jet to the coastal flow, thus enhancing the branching feature even in the presence of bottom friction. We plan to assess the model predictions using hydrographic and altimeter data from the Japan Sea.

Generation of Tsushima eddies: Through a reduced gravity model, we are proposing a novel mechanism of eddy generation when a buoyant flow interacts with a curved boundary. As the boundary curves into the current, the vorticity conservation would weaken the coastal velocity, which may become stagnant, beyond which point eddies will be generated to accommodate the upstream flux. We are presently using the Lamont Ocean model to numerically demonstrate the process, which may be relevant to the generation of the Tsushima and possibly other eddies.

TRANSITIONS

The Tsushima Current research will be linked to the rest of the JES program results. The annual JES workshops (see: http://sam.ucsd.edu/onr_jes) provide opportunity to develop such transitions.

RELATED PROJECTS

none

PUBLICATIONS

Gordon, A. L., C. F. Giulivi, C. M. Lee, H. H. Furey, A. Bower and L. Talley (2002) Japan/East Sea Intra-thermocline Eddies. *Jour of Phys Oceanogr.* (in press)

Ou, H. W. (2001): A model of buoyant throughflow: With application to branching of the Tsushima Current. *J. Phys. Oceanogr.*, 31, 115-126.

Ou, H. W. and A. Gordon (2001): Subduction along a mid-ocean front and the generation of intra-thermocline eddies: a theoretical study. *J. Phys. Oceanogr.*, in press.